

PCT

RECEIVED OCT 28 1994  
WORLD INTELLECTUAL PROPERTY ORGANIZATION  
International Bureau



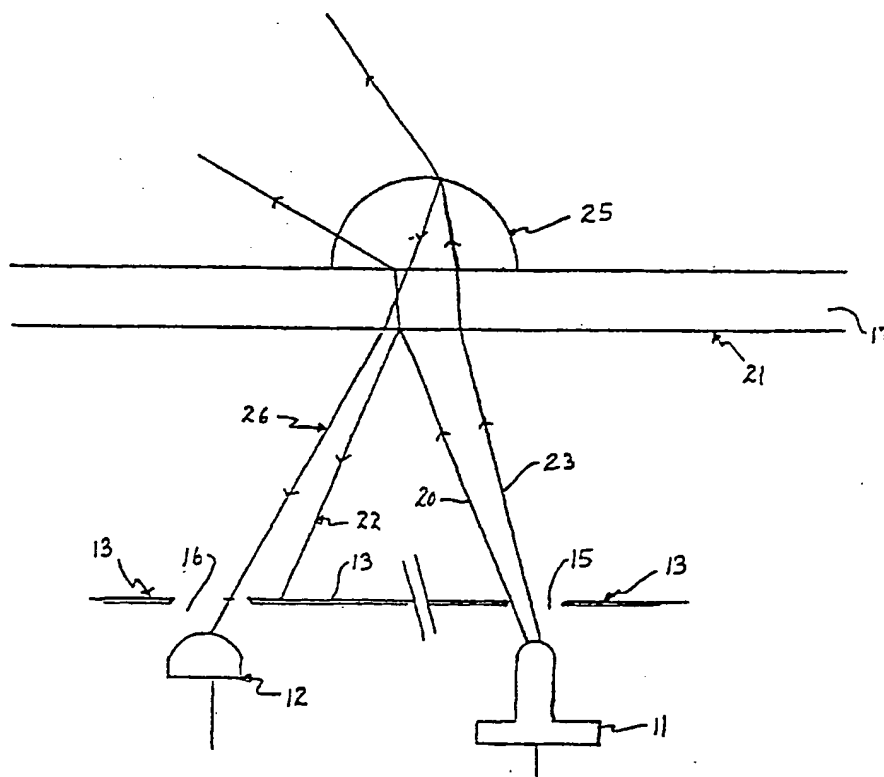
INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 5 : <b>G08B 21/00</b>		(11) International Publication Number: <b>WO 94/27262</b>
A1		(43) International Publication Date: 24 November 1994 (24.11.94)
(21) International Application Number: <b>PCT/US94/05093</b>		(81) Designated States: European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).  Published With international search report.
(22) International Filing Date: 6 May 1994 (06.05.94)		
(30) Priority Data: 08/059,597 7 May 1993 (07.05.93) US		
(71)(72) Applicant and Inventor: <b>HEGYI, Dennis, J. [US/US];</b> 1708 Morton Avenue, Ann Arbor, MI 48104 (US).		
(74) Agents: <b>ROHM, Benita, J. et al.; Rohm &amp; Monsanto, 512</b> Springfield Avenue, Cranford, NJ 07016 (US).		

(54) Title: MULTI-FUNCTION LIGHT SENSOR FOR VEHICLE

(57) Abstract

A system for detecting the presence of rain droplets on a windshield (17) employs a source of light, such as an LED (11), and a photodetector (12) installed on the dashboard (13) of a vehicle. The LED (11) and the photodiode (12) are arranged with respect to one another such that light from the LED (11) cannot reflect directly off the windshield into the photodiode (12). Only when the light from the LED is backscattered by an environmental condition, such as the raindrops (25) on the exterior of the windshield (17), the condensation of moisture on the interior of the windshield (17), or the presence of smoke in the cabin, will the photodiode (12) receive the light from the LED (11). Each of these environmental conditions has a predetermined characteristic signature which permits the processing of data to detect same. An ambient light signal is subtracted from the combination of the rain and ambient light signals by pulsed operation of the LED (11) and subtracting the ambient light signal, which is detected when the LED (11) is dark, from the combined LED (11) and ambient light signal which is present when the LED (11) is illuminated.



*FOR THE PURPOSES OF INFORMATION ONLY*

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AT	Austria	GB	United Kingdom	MR	Mauritania
AU	Australia	GE	Georgia	MW	Malawi
BB	Barbados	GN	Guinea	NE	Niger
BE	Belgium	GR	Greece	NL	Netherlands
BF	Burkina Faso	HU	Hungary	NO	Norway
BG	Bulgaria	IE	Ireland	NZ	New Zealand
BJ	Benin	IT	Italy	PL	Poland
BR	Brazil	JP	Japan	PT	Portugal
BY	Belarus	KE	Kenya	RO	Romania
CA	Canada	KG	Kyrgyzstan	RU	Russian Federation
CF	Central African Republic	KP	Democratic People's Republic of Korea	SD	Sudan
CG	Congo	KR	Republic of Korea	SE	Sweden
CH	Switzerland	KZ	Kazakhstan	SI	Slovenia
CI	Côte d'Ivoire	LI	Liechtenstein	SK	Slovakia
CM	Cameroon	LK	Sri Lanka	SN	Senegal
CN	China	LU	Luxembourg	TD	Chad
CS	Czechoslovakia	LV	Latvia	TG	Togo
CZ	Czech Republic	MC	Monaco	TJ	Tajikistan
DE	Germany	MD	Republic of Moldova	TT	Trinidad and Tobago
DK	Denmark	MG	Madagascar	UA	Ukraine
ES	Spain	ML	Mali	US	United States of America
FI	Finland	MN	Mongolia	UZ	Uzbekistan
FR	France			VN	Viet Nam
GA	Gabon				

## MULTI-FUNCTION LIGHT SENSOR FOR VEHICLE

### BACKGROUND OF THE INVENTION

#### FIELD OF THE INVENTION

This invention relates generally to systems and arrangements for determining  
5 the presence of a plurality of environmental conditions in relation to a vehicle, and  
more particularly, to a system which can control the operation of a device, such as  
the windows, the convertible roof, the air conditioner, a dehumidifier, the ventilation  
system, or the windshield wipers of a vehicle, in response to the presence of droplets  
of liquid on a transparent surface thereof, such as the windshield of the vehicle, the  
10 presence of condensation on the interior of the windshield of the vehicle, or the  
presence of smoke in the vehicle.

#### DESCRIPTION OF THE RELATED ART

Numerous efforts have been made in the prior art to provide a system which  
reliably will control the windshield wipers of a vehicle in response to the presence  
15 of water on the windshield. In addition to failing to meet the level of reliability  
required to avoid the annoying and distracting false triggering of windshield wipers,  
the majority of the known arrangements must be installed directly onto the  
windshield, resulting in unsightly wiring extending from a sensor which has been  
bonded to the interior of the windshield. With respect to the false triggering of the  
20 windshield wipers, many of the known arrangements will trigger a false indication  
of rain in response to fluctuations in the ambient light, as would be the case with a  
vehicle traveling under the shadows of telephone poles, or under highway lamps.

Existing optical rain sensors of the type which are usually installed within  
vehicles are mounted on the windshield in the wiper path. Optical sensors generally  
25 include a light source, such as an LED, and a photodetector, usually a phototransistor  
or a photodiode, arranged such that when no raindrops are on the windshield, light  
from the LED is totally internally reflected at the outside surface of the windshield  
to a photodiode. If a drop of rain is deposited on the windshield where the light  
beam is reflected, the conditions for total internal reflection are violated, and the  
30 intensity of light in the reflected beam is reduced. In these known systems, a

relatively large array of LEDs and photodiodes are required to monitor a few square inches on the windshield. The extent of the monitored region of the windshield must be sufficiently large to provide an accurate sample of the random distribution of raindrops which fall on the surface of the windshield. As stated, the array of LEDs and photodiodes must be mounted inside the vehicle on the windshield in the wiper path.

Another problem associated with known arrangements is that of cost. In most of the presently available designs, one photodetector is required for each LED in the array. There is, therefore, a need for a rain sensor which is economical and which need not be installed on the windshield of the vehicle.

In addition to water depositing on the outer surface of the windshield, water will collect on the interior of the windshield in the form of condensed water vapor. Such condensed water vapor can, within a matter of minutes, reduce the visibility through the window to a dangerous level. In such situations, it is essential that the defogger function be carried out by cycling the air conditioner to dehumidify the air. The operation of the air condition generally will decrease the amount of fog on the interior of the windshield in a relatively short period of time.

It is additionally useful in a vehicle to reduce the accumulation of smoke in the cabin of the vehicle which would result from the smoking of tobacco by the occupants. On occasion, the operator of the vehicle would be reluctant to embarrass a smoking passenger by obvious manipulation of the ventilator controls. Accordingly, it would be desirable for the ventilator to be operated automatically in response to the presence of smoke in the cabin.

It is, therefore, an object of this invention to provide an arrangement which is simple and will reliably detect the presence of water droplets on the outside of a windshield of a vehicle.

It is another object of this invention to provide an arrangement which is simple and will reliably detect the presence of condensed water vapor on the inside of a windshield of a vehicle.

It is also an object of this invention to provide an arrangement which is simple and will reliably detect the presence of smoke in the cabin of a vehicle.

It is a further object of this invention to provide a system for automatically operating the windshield wipers of a vehicle in response to the presence of water on the windshield.

It is additionally an object of this invention to provide a system for automatically operating an air conditioning or dehumidification system of a vehicle in response to the presence of condensed water vapor on the windshield.

It is yet a further object of this invention to provide a system for automatically operating the cabin ventilation system of a vehicle in response to the presence of smoke, such as cigarette smoke, in the cabin of the vehicle.

It is also another object of this invention to provide a system which responds to the effect on light by several environmental conditions, while maintaining immunity to variations in the ambient light levels.

It is yet an additional object of this invention to provide a system which responds to the effect on light by several environmental conditions, in the vicinity of the windshield of the vehicle, without the need for establishing a direct contact between the system and the windshield.

It is still another object of this invention to provide a windshield wiper control sensor which need not be installed directly on the windshield of the vehicle.

It is a yet further object of this invention to provide a windshield wiper control sensor which can be installed on the dashboard of the vehicle.

## SUMMARY OF THE INVENTION

The foregoing and other objects are achieved by this invention which provides apparatus and method for controlling the operation of the windshield wipers of a vehicle in response to the deposition of water on the exterior of the windshield; the operation of the air conditioning system in response to the formation of water condensation on the interior of the windshield of the vehicle; and the operation of the ventilator system in response to the presence of smoke in the cabin of the vehicle.

In accordance with a first aspect of the invention, an arrangement is provided for detecting the presence of water droplets on the windshield of a vehicle. A light source produces a radiant energy and directs same toward the windshield. A first reflected portion of the radiant energy is reflected by the windshield, and a second  
5 portion of the radiant energy is scattered by the water droplets on the windshield. A light sensor having an input for receiving an ambient light and a received portion of the second reflected portion of the radiant energy from the light source is additionally provided. The reflected portion of the radiant energy has an amplitude which is responsive to the number of water droplets on the windshield. The light  
10 sensor further has a sensor output for producing a sensor output electrical signal which is responsive to the light received at the input. There is additionally provided a circuit which is coupled to the sensor output for providing a first electrical signal responsive to the received portion of the second reflected portion of the radiant energy from the light source. The sensor output also produces a second electrical  
15 signal which is substantially responsive to the ambient light.

In a specific illustrative embodiment of the invention, the second reflected portion of the radiant energy corresponds substantially to the proportion of the windshield which is covered by the water droplets.

In a highly advantageous embodiment of the invention, the circuit is provided  
20 with a driver which is coupled to the light source means. The driver produces a cyclical enabling signal having sequential first and second states for causing the light source to produce the radiant energy only during intervals of time that the cyclical enabling signal is in the first state. The circuit may be provided with an amplifier coupled to the sensor output for producing an amplified signal corresponding to the  
25 electrical signal responsive to the light which is received at the input of the light sensor.

A phase-responsive device is coupled to the amplifier and to the driver for producing a time-varying signal which is responsive to a difference between the magnitude of the sensor output electrical signal when the cyclical enabling signal is  
30 in the first state, and the magnitude of the sensor output electrical signal when the

cyclical enabling signal is in the second state. In one embodiment, first and second amplifier stages are provided, each having a predeterminable gain characteristic. The first and second amplifier stages are AC-coupled to one another.

5 In a still further embodiment of the invention, there is provided an integrator coupled to the phase-responsive device for integrating the time-varying signal over time to produce a rain signal. The integrator has an integration time constant characteristic which is longer than a cycle of the cyclically enabling signal. There is additionally provided a processor having a plurality of inputs for receiving the rain signal and the second electrical signal which is substantially responsive to the ambient light. A control signal is produced at the output of the processor. The responsiveness of the overall device to the quantum of water droplets on the windshield is adjustable with a sensitivity control which is coupled to the processor. 10 The control signal is used to operate the windshield wiper.

In certain embodiments of the invention, a windshield wiper timer is employed to produce a signal which is responsive to the duration of a wipe cycle of the windshield wiper. This is useful to determine whether the windshield is wet or dry, since a wipe cycle generally will take longer on a dry windshield. 15

The control signal at the output of the processor is not limited to operation of the windshield wipers. In some embodiments of the invention, the control signal may be applied to operate a window, such as a power window, which would be closed in the event rain is detected. In other embodiments, the control signal may be employed to operate a convertible top, which would be closed in response to the detection of rain.. 20

In a preferred embodiment of the invention, the cyclical enabling signal has a frequency within a range of approximately between 5 kHz and 100 kHz. The integration time constant has a value of approximately between 0.5 ms and 250 ms. In addition, a structure, which may be in the form of a light baffle with one or more apertures therethrough for controlling or otherwise defining the field of view of the light sensor, may be employed, particularly with respect to the light sensor. 25

In accordance with a further aspect of the invention, an arrangement is provided for producing a controlled signal in response to the presence of liquid droplets on a first surface of a translucent material. In accordance with this further aspect of the invention, a light source produces a radiant energy and directs same toward at least a portion of a second surface of the translucent material. A first portion of the radiant energy is reflected by the translucent material, and a second portion of the radiant energy is scattered by the water droplets on the translucent material. A light sensor having an input for receiving an ambient light and a received portion of the second portion of the radiant energy from the light source, is provided. The second portion of the radiant energy has an amplitude which is responsive to the number of water droplets on the first surface of the translucent material. The light sensor is further provided with a sensor output for producing a sensor output electrical signal which is responsive to the light received at the input. A cyclical driver is coupled to the light source for causing same to produce the radiant energy during a portion of a cycle, at a predetermined cycle frequency. In addition, control signal circuitry which is coupled to the light sensor and to the cyclical driver produces a control signal in response to a differential between the magnitude of the sensor output electrical signal when the light source is illuminated, and the magnitude of the sensor output electrical signal when the light source is dark, during a cycle of the cyclical driver.

In a specific embodiment of this aspect of the invention, there is provided circuitry for producing an ambient light signal which is substantially responsive to an ambient light impinging on the input of the light sensor. A controller produces a controller signal which is responsive to the ambient light signal and the control signal produced by the control signal circuitry. Additionally, there is provided a sensitivity adjustment which is coupled to the controller for adjusting the sensitivity of the arrangement with respect to the number of water droplets on the first surface of the translucent material.



In accordance with a first method aspect of the invention, a process is applied to produce a signal which is responsive to the droplets of liquids on a first surface of a translucent material. The method is provided with the steps of:

5 illuminating a second surface of the translucent material with a cyclically varying light which is in an illuminated state for a first portion of a cycle and dark for a second portion of said cycle;

receiving at a light sensor an ambient light and a portion of the cyclically varying light which is scattered by the droplets of the liquid on the first surface of the translucent material, and producing at an electrical output of the light sensor a  
10 sensor signal corresponding to the light received by the light sensor; and

producing a difference signal responsive to the difference in the magnitude of the sensor signal between the first and second portions of said cycle.

In accordance with a further method aspect of the invention, the inventive method produces a plurality of signals, each responsive to a predetermined  
15 environmental condition of a vehicle of the type having a windshield, the method comprising the steps of:

energizing a source of illumination whereby electromagnetic energy is directed toward an interior surface of the windshield, the electromagnetic energy being in the form of a cyclically varying light which is in an illuminated state for a first portion  
20 of a cycle and dark for a second portion of said cycle;

receiving at a light sensor an ambient light and a portion of the cyclically varying light which has been scattered in response to the environmental condition; and

producing at an electrical output of the light sensor a sensor signal  
25 corresponding to the light received by the light sensor.

In one embodiment of this further method aspect of the invention, the environmental condition is in the form of water droplets which are deposited on the exterior of the windshield. In another embodiment of the invention, the environmental condition is water vapor condensing on the interior of the windshield. In this  
30 embodiment, the cyclically varying light is scattered by the condensed water vapor.

In a still further embodiment of the invention, the environmental condition is the presence of smoke particles in the vehicle, in the path between the source of illumination and the light sensor. In such an embodiment, the cyclically varying light is scattered by the smoke particle.

5           It is important to recognized that any one or all of the aforementioned environmental conditions which are detected, can be detected by the same structure. The identification of the particular environmental condition which is present with respect to the vehicle is determinable by software. For example, when a car is operated in a defogger mode where the defogger function is carried out by cycling  
10       the air conditioner to dehumidify the air, it is observed that when the relative humidity inside the car is such that moisture condenses out on the windshield, the amount of fog on the windshield increases until the air conditioner cycles on after which the fog level rapidly decreases. One feature which is characteristic of the process is that the time for moisture to buildup is always longer than the time for the  
15       moisture to evaporate from the windshield. The time for moisture to buildup is rarely less than about 20 seconds, and could last several minutes, while the evaporation can occur over a time from a few seconds to perhaps over a minute.

          Smoking has a characteristic signature, which is distinct, but not quite as distinct as for moisture condensing on the windshield. Smoking has a time scale of  
20       significant variations within a few seconds. Also, the time for smoke to buildup is always smaller than the time for it to dissipate.

          With respect to a signal for condensing moisture and fog, as detected by a rain detector structure, as will be described herein, it is noted that moisture  
condensing out on the windshield scatters light back from the light source, which  
25       may be in the form of LEDs, which is superimposed on the rain signal and detected by the photodiode after passing through a lock-in amplifier. Also, smoke which passes between the LED and the windshield will increase the amount of backscattered radiation detected by the photodiode after passing through the lock-in amplifier, and will be superimposed on the rain signal. In such an embodiment which is subjected  
30       to all three types of environmental conditions, software can be applied to separate out

the three different signals, *i.e.*, rain, fog, and smoke, without the confusion of triggering on the windshield wipers in the presence of only fog and smoke.

## BRIEF DESCRIPTION OF THE DRAWING

Comprehension of the invention is facilitated by reading the following detailed description, in conjunction with the annexed drawing, in which:

Fig. 1 is a schematic representation of certain elements of structure which are arranged in accordance with the principles of the invention;

Fig. 2 is a function block representation of circuitry used in combination with the structure of Fig. 1 to produce signals corresponding to the presence of rain or fog on the windshield, or smoke, and the magnitude of the impinging ambient light;

Fig. 3 is a function block representation of a microprocessor which receives the signals generated by the structure in Fig. 2 and controls a windshield wiper control unit;

Fig. 4 is a schematic representation of a circuit which can be employed in the embodiment of Fig. 2; and

Fig. 5 is a schematic representation of circuitry which drives a light emitting diode in response to a clock.

## DETAILED DESCRIPTION OF THE INVENTION

Fig. 1 is a schematic representation of certain elements of structure configured in accordance with the principles of the invention. More specifically, a light source, in the form of LED 11 and a photodiode 12 are arranged beneath a baffle 13 having an aperture 15 therethrough for LED 11 and an aperture 16 for photodiode 12. Baffle 13 may be the top surface of the dashboard (not shown) of a vehicle (not shown). As will be discussed hereinbelow, apertures 15 and 16 are configured to prevent light from being reflected directly to the photodiode by the windshield.

The operation of baffle 13 with apertures 15 and 16 therethrough is illustrated in Fig. 1. As shown, a light ray 20 is propagated from LED 11 and impinges upon

inner surface 21 of windshield 17. The light ray is reflected back as a reflected ray 22, which is shown in the figure to impinge upon baffle 13. Some of the light from LED 11, such as light ray 23, impinges upon inner surface 21 of the windshield, where it is refracted into and through the windshield to a raindrop 25. The raindrop backscatters the light along a backscattered ray 26 which is propagated through apertures 16 and into photodiode 12. Thus, it can be seen that the light from LED 11 is directed to photodiode 12 only after being backscattered, such as by a raindrop. The intensity of light reflected at an interface is related to the ratio of the indices of refraction of the two media on opposite sides of the interface. The index of refraction of most glasses is about 1.5, while the index of refraction of water is 1.33, and the index of refraction of air is 1.00. When a raindrop is present, instead of a reflection arising at the outer surface of the windshield because without the raindrop the discontinuity in the index of refraction between the glass and air is relatively large, the light from the LED is transmitted into the raindrop and the reflection occurs at the discontinuity of the index of refraction at the curved air-water interface at the outer surface of the raindrop. This surface reflects light back into the vehicle over a large angular range, some of the rays striking the photodiode.

The photodiode signal is proportional to the fractional area of the windshield covered by raindrops which is relatively similar to the way human vision is interfered with by raindrops. The angular range over which light is reflected depends upon the cross-sectional width of the raindrop at the water-glass interface, *i.e.*, the diameter of the part of the raindrop touching the glass, and, to the extent that its outer surface can be approximated as a sphere, by the radius of that sphere. If the width-to-radius ratio were the same for different size raindrops, they would all reflect light over the same angular range. Assuming spherical raindrops with the same width-to-radius ratio, the amount of light reflected into a given direction depends only on the cross-sectional contact area of the raindrop. Thus, the total amount of light reflected back into the photodetector is proportional to the area of the glass covered by raindrops. Also, the visual obscuration of the rain is approximately proportional to the area covered by the raindrops. From this, one can conclude that the intensity of light reflected by

raindrops on a windshield back to the photodiode is a good measure of the obscuration caused by rain that a driver experiences and that the signal detected by this rain sensor is an appropriate one to gage the visual perception of rain by a driver.

The rain detector system of the present invention must work under a variety of conditions. Occasionally, the sun is shining when it is raining, and the LED light reflected by raindrops must be detectable in sunlight. This is achieved by modulating LED 11 at a reference frequency and picking out the photodiode current at the same frequency in phase with the modulated LED light using a type of phase-sensitive amplifier, sometimes referred to as a lock-in amplifier.

Referring once again to Fig. 1, light rays 20 and 23 are shown to exit LED 11. As previously described, light ray 20 is reflected from inner surface 21 of windshield 17 and is propagated through aperture 16 of the photodiode. Any ray which exits further to the left will strike aperture 15 of LED 11, and therefore, one is assured that no rays which are directly reflected by the windshield will reach photodiode 12. However, it is possible that a ray from LED 11 will be scattered twice and reach the photodiode. With reasonable care being paid to designing the apertures, relatively little of the light will reach the photodiode by scattering or by light reflecting from objects other than raindrops. Even if some light not scattered by raindrops reaches the photodiode, it does not significantly prevent the detection of raindrops. It does, however, decrease the dynamic range of the detector. The electronics, which will be described hereinbelow, will saturate with a smaller amount of rain on the windshield because some of the dynamic range is taken up by light scattered by other objects. Also as will be described hereinbelow, some light may be scattered by the presence of condensed water vapor (not shown) on inner surface 21 of windshield 17, or the presence of smoke (not shown) in the cabin of the vehicle.

Fig. 2 is a function block representation of an electronic system which is constructed in accordance with the principles of the invention. The electronics described with respect to this figure will detect the tiny fraction of the LED's light that reaches the photodiode in the large ambient light background, which can include

full sunlight. Referring to Fig. 2, a clock 30 drives an LED driver 31 which is coupled to an LED array 32. LED array 32 bears analogous correspondence to LED 11 in Fig. 1. As shown in Fig. 2, the light from LED array 32 is propagated through windshield 17 and scattered in raindrop 25 so as to be reflected to photodiode 12.

5           Clock 30 and LED driver 31 function in combination to produce a square wave output (not shown) whereby the LED array is turned on for half of the clock period. The portion of the light propagated from LED array 32 which is received at photodiode 12 is converted into a current signal which is provided at an input of a transimpedance amplifier 35. The output of transimpedance amplifier 35 is a voltage  
10           which is proportional to the photodiode current. This voltage signal is then conducted to an amplifier 36. The output of amplifier 36 is conducted to a gain stage 37 which has a controllable gain of +1 or -1, and is used to separate the signal from the background. As shown, gain stage 37 has inputs for receiving phase references from clock 30. The gain is set to +1 when the LED is on, and to -1 when the LED  
15           is off. Since the ambient light is the same during the two halves of the clock period, the sum of the two halves is (rain signal + ambient light) when the gain is +1 and (-ambient) when the gain is -1. When these are added together, the result is the rain signal, i.e., (rain signal + ambient) + (-ambient) = rain signal.

          An averaging stage 38 produces an average over time  $\tau$  which is long  
20           compared to a clock period. The addition described hereinabove which separates the rain signal from the ambient background occurs in averaging stage 38. An output amplifier 39 provides additional gain and produces at its output the rain signal.

          In order to change the sensitivity of the rain detector to correspond to night  
driving conditions for which the eye is more disturbed by rain on the windshield, an  
25           ambient light signal is derived from the output of transimpedance amplifier 35. During daytime operation, the ambient light generates a much larger current in the photodiode than the light backscattered by the raindrops so that the output of the transimpedance amplifier is approximately a measure of the ambient light signal. During low sky brightness conditions, the amplitude of the ambient light signal is

reduced. That information is sent to a microprocessor, as will be described hereinbelow.

Fig. 3 is a function block representation of a microprocessor 40 coupled at an output thereof to a wiper control 41. Microprocessor 40 is provided with an analog-to-digital convertor (not shown) which changes the threshold level rain signal necessary to generate a wipe to be reduced. In addition, microprocessor 40 provide control signals for the ventilator and dehumidifier controls.

Another situation for which the threshold level necessary to generate a wipe by the wipers should be reduced is when large drops of rain strike the windshield. For a given area of the windshield covered by small or large raindrops, large drops are visually much more distracting to a driver. A mathematical expression sensitive to the fractionally larger statistical fluctuations of large drops versus small drops can be written as:

$$Q = \frac{\sum_{i=1}^n (m_i - m_{ave})^2}{n(m_{ave})^2} \quad (\text{Eq. 1})$$

Here,  $m_i$  is the change in the rain signal between the  $i^{\text{th}}$  time element and the  $(i - 1)$  time element that occur between two successive passages of the wiper blade past the rain sensor, and  $m_{ave}$  is the average value of  $m_i$  over the interval between two successive wipes. The quantity  $Q$  is the square of the standard deviation of  $m_i$  normalized by  $(m_{ave})^2$  in order to make a dimensionless ratio. For larger raindrops which are characterized by larger fluctuations,  $Q$  is larger than for small drops and may be used to reduce the threshold level of the rain signal necessary to generate a wipe. Also, Fig. 3 shows three inputs to the microprocessor: the rain signal, the ambient light signal, and a separate input set by the driver (not shown) to adjust the threshold amount of rain that generates an output to the wiper control which initiates a wipe.

There are times when it is difficult to tell when the windshield is wiped clean of all water. For example, if the water is a thin, very smooth sheet, it will scatter

little radiation to the photodetector. Another way of getting an independent measure of the dryness of a windshield is by monitoring the time between successive wipes of a windshield wiper. As the windshield gets drier, there is more friction between the wiper and the glass, and the wiper motor slows down increasing the time between  
5 wipes. Monitoring the time between successive passages of the wiper blade in front of the rain sensor, the passage of the wiper appears as a very large amplitude signal which last for a small fraction of the time between wipes. This characteristic can be used by microprocessor 40 to determine whether the windshield is dry enough to shut down the wiper.

10 Fig. 4 is a schematic representation of an electrical circuit for a phase-sensitive amplifier. As previously stated, photodiode 12 generates a current in transimpedance amplifier 35. In this specific illustrative embodiment, transimpedance amplifier 35 is formed of an amplifier 50 with a feedback resistor 51. Amplifier 50 produces at its output the ambient light signal. In this embodiment, feedback resistor  
15 51 has a value of 56 k $\Omega$ . The transimpedance amplifier is AC-coupled via a capacitor 52 to amplifier 36 which is formed of an amplifier 53 which is AC-coupled to a further amplifier 54. Amplifier 53 has a gain of 100, as does amplifier 54.

Amplifier 36 is coupled at its output to gain stage 37 which is provided with a plurality of switches 56 which are set by the complementary outputs of clock 30,  
20 which will be described hereinbelow with respect to Fig. 5.

Referring for the moment to Fig. 5, this figure is a schematic representation of clock 30 and LED driver 31. As shown, clock 30 is formed of an oscillator 60 which is coupled at its output to a type D flip-flop 61. Flip-flop 61 has complementary outputs 62 and 63, output 63 being coupled to LED driver 31, which is in the  
25 form of a transistor 64. Transistor 64 drives LED array 32, as described herein.

Referring once again to Fig. 4, switches 56 are opened and closed in response to outputs 62 and 63 of flip-flop 61 to provide the gain of +1 and -1, as described hereinabove with respect to Fig. 2. Gain stage 37 is coupled to averaging circuit 38 which is based on an RC design such that the averaging timer  $\tau = RC$ . In this  
30 circuit, R consists of two 1.1 K $\Omega$  resistors in series so that  $R = 2.2 \text{ K}\Omega$ , and  $C = 5$



$\mu\text{F}$ , so that  $\tau = 11$  ms. Output amplifier stage 39 provides a final gain of 10, and provides the rain signal, as well as the fog and smoke signals, at an output 66 thereof.

As previously described, the present invention is useful to determine the presence of condensed water vapor on the interior surface of the windshield, and smoke in the cabin of the vehicle. In embodiments of the invention where it is desired to determine the presence of condensation on the windshield or smoke, the present invention is operated to separate out the three signals, rain, fog, and smoke, and not get confused by the windshield wipers going back and forth.

The logic behind this process is as follows. The lowest level signal coming out of the lock-in amplifier is stored as a "clean" windshield signal." Thus, the passing back and forth of the windshield wipers does not confuse the data processing when there is a rapid increase in signal (one with a rise and fall time of about 100 ms) is easily recognized and excluded from the data that is analyzed. The moisture signal rises linearly from the clean windshield level with a characteristic time of from 20 seconds to several minutes. It has an amplitude which is many times larger than the largest rain signal so that it will not be confused with the buildup of rain on the windshield. Also, when the wipers are wiping, the moisture signal will not change when the wipers pass. Mostly, when there is condensing moisture on the glass, it is raining so there are a variety of conditions that must be satisfied for the microprocessor to have detected an interior fog condition. The confirming signature is that when fog is detected condensing on the windshield which causes the air condition to turn on, the signal (lock-in amplifier output signal) should decrease rapidly (the time scale is short compared to the time required for the fog to buildup) to the clean window level. In terms of the output signal going to the air conditioner, it could be either a binary signal when a predetermined level of fog is detected, or it could be a calibrated signal which is proportional to the amount of fog on the windshield and would be used to turn the dehumidifier on and off.

The smoke detecting process is similar to that described above. After the wiper passage is removed from the signal (the output signal from the lock-in

amplifier), a large rapid variation with a time scale of from 250 ms to 5 seconds is the first condition that must be satisfied by a smoke signal. These times are clearly distinct from the passage of the wipers and from variation due to fog. In addition, these signals are many times larger than any rain signal or splash, and constitute the  
5 second condition that must be satisfied. Also, the time for the smoke signal to increase is always less than the time for it to decrease, the third condition. It is more difficult to make a signal output proportional to the amount of smoke. It would be preferable to have a binary output that is used to control the admission of outside air into the passenger compartment.

10 Although the invention has been described in terms of specific embodiments and applications, persons skilled in the art can, in light of this teaching, generate additional embodiments without exceeding the scope or departing from the spirit of the claimed invention. Accordingly, it is to be understood that the drawing and description in this disclosure are proffered to facilitate comprehension of the  
15 invention and should not be construed to limit the scope thereof.

**WHAT IS CLAIMED IS:**

1. An arrangement for detecting the presence of water droplets on a windshield of a vehicle, the arrangement comprising:

5 light source means for producing a radiant energy and directing same toward the windshield, a first portion of said radiant energy being reflected by the windshield, and a second portion of said radiant energy being scattered by the water droplets on the windshield;

10 light sensor means having an input for receiving an ambient light and a received portion of said second portion of said radiant energy from said light source means, said second portion of said radiant energy having an amplitude which is responsive to the number of water droplets on the windshield, said light sensor means further having a sensor output for producing a sensor output electrical signal responsive to light received at said input; and

15 circuit means coupled to said sensor output for producing a first electrical signal responsive to said received portion of said second portion of said radiant energy from said light source means, and a second electrical signal substantially responsive to said ambient light.

20 2. The arrangement of claim 1 wherein said second portion of said radiant energy corresponds substantially to the proportion of the windshield which is covered by the water droplets.

25 3. The arrangement of claim 1 wherein said circuit means comprises driver means coupled to said light source means, said driver means producing a cyclical enabling signal having sequential first and second states for causing said light source means to produce said radiant energy only during intervals of time that said cyclical enabling signal is in said first state.

4. The arrangement of claim 3 wherein said circuit means comprises:

amplifier means coupled to said sensor output for producing an amplified signal corresponding to said electrical signal responsive to light received at said input of said light sensor means; and

phase-responsive means coupled to said amplifier means and to said driver means for producing a time-varying signal responsive to a difference between the magnitude of said sensor output electrical signal when said cyclical enabling signal is in said first state and the magnitude of said sensor output electrical signal when  
5 said cyclical enabling signal is in said second state.

5. The arrangement of claim 4 wherein said amplifier means comprises: first and second amplifier stages, each having a predeterminable gain characteristic; and  
ac coupling means for coupling said first and second amplifier stages to one  
10 another.

6. The arrangement of claim 4 wherein there is further provided integration means coupled to said phase-responsive means for integrating said time-varying signal over time to produce a rain signal, said integration means having an integration time constant characteristic which is longer than a cycle of said cyclically  
15 enabling signal.

7. The arrangement of claim 6 wherein there is further provided processor means having a plurality of inputs for receiving said rain signal and said second electrical signal substantially responsive to said ambient light, for producing at a processor output thereof a control signal.

20 8. The arrangement of claim 7 wherein there is further provided sensitivity control means coupled to said processor means for producing a sensitivity signal for predetermining a quantum of water droplets characteristic of said control signal.

9. The arrangement of claim 6 wherein the vehicle is provided with a windshield wiper, and there is further provided windshield wiper control means for  
25 operating a windshield wiper in response to said control signal.

10. The arrangement of claim 9 wherein there is further provided windshield wiper timing means for producing a signal responsive to the duration of a wipe cycle of the windshield wiper.

11. The arrangement of claim 6 wherein the vehicle is provided with a window, and there is further provided window control means for operating the window in response to said control signal.

12. The arrangement of claim 6 wherein the vehicle is provided with an  
5 openable top, and there is further provided openable top control means for operating the openable top in response to said control signal.

13. The arrangement of claim 6 wherein the vehicle is provided with a convertible top, and there is further provided a convertible top control means for operating the convertible top in response to said control signal.

10 14. The arrangement of claim 6 wherein said cyclical enabling signal has a frequency within a range of approximately between 5 kHz and 100 kHz, and said integration time constant has a value of approximately between 0.5 ms and 250 ms.

15. The arrangement of claim 1 wherein there is further provided means for defining a field of view of said light sensor means.

15 16. An arrangement for producing a control signal in response to the presence of liquid droplets on a first surface of a translucent material, the arrangement comprising:

light source means for producing a radiant energy and directing same toward at least a portion of a second surface of the translucent material, a first portion of  
20 said radiant energy being reflected by the translucent material, and a second portion of said radiant energy being scattered by the water droplets on the translucent material;

light sensor means having an input for receiving an ambient light and a received portion of said second portion of said radiant energy from said light source  
25 means, said second portion of said radiant energy having an amplitude which is responsive to the number of water droplets on the first surface of the translucent material, said light sensor means further having a sensor output for producing a sensor output electrical signal responsive to light received at said input;

cyclical driver means coupled to said light source means for causing said light source means to produce said radiant energy during a portion of a cycle, at a predetermined cycle frequency;

5 control signal means coupled to said light sensor means and to said cyclical driver means for producing the control signal in response to a differential between the magnitude of said sensor output electrical signal when said light source means is illuminated and the magnitude of said sensor output electrical signal when said light source means is dark, during a cycle of said cyclical driver means.

10 17. The arrangement of claim 16 wherein there is further provided means for producing an ambient light signal which is substantially responsive to an ambient light impinging on said input of said light sensor means.

18. The arrangement of claim 17 wherein there is further provided controller means for producing a controller signal responsive to said ambient light signal and the control signal produced by said control signal means.

15 19. The arrangement of claim 18 wherein there is further provided sensitivity adjustment means coupled to said controller means for adjusting the sensitivity of the arrangement to the number of water droplets on the first surface of the translucent material.

20 20. A method of producing a signal responsive to droplets of a liquid on a first surface of a translucent material, the method comprising the steps of:

illuminating a second surface of the translucent material with a cyclically varying light which is in an illuminated state for a first portion of a cycle and dark for a second portion of said cycle;

25 receiving at a light sensor an ambient light and a portion of the cyclically varying light which is scattered by the droplets of the liquid on the first surface of the translucent material, and producing at an electrical output of the light sensor a sensor signal corresponding to the light received by the light sensor; and

producing a difference signal responsive to the difference in the magnitude of the sensor signal between the first and second portions of said cycle.

21. A method of producing a plurality of signals, each responsive to a predetermined environmental condition of a vehicle of the type having a windshield, the method comprising the steps of:

energizing a source of illumination whereby electromagnetic energy is directed  
5 toward an interior surface of the windshield, the electromagnetic energy being in the form of a cyclically varying light which is in an illuminated state for a first portion of a cycle and dark for a second portion of said cycle;

receiving at a light sensor an ambient light and a portion of the cyclically  
varying light which has been scattered in response to the environmental condition;  
10 and

producing at an electrical output of the light sensor a sensor signal  
corresponding to the light received by the light sensor.

22. The method of claim 21 wherein said environmental condition is water  
droplets being deposited on the exterior of the windshield, and said cyclically varying  
15 light in said step of receiving is scattered by said water droplets.

23. The method of claim 21 wherein said environmental condition is water  
vapor condensing on the interior of the windshield, and said cyclically varying light  
in said step of receiving is scattered by said condensed water vapor.

24. The method of claim 21 wherein said environmental condition is the  
20 presence of smoke particles in the vehicle and interposed in a light path between the source of illumination and the light sensor, and said cyclically varying light in said step of receiving is scattered by said smoke particles.

FIG. 1

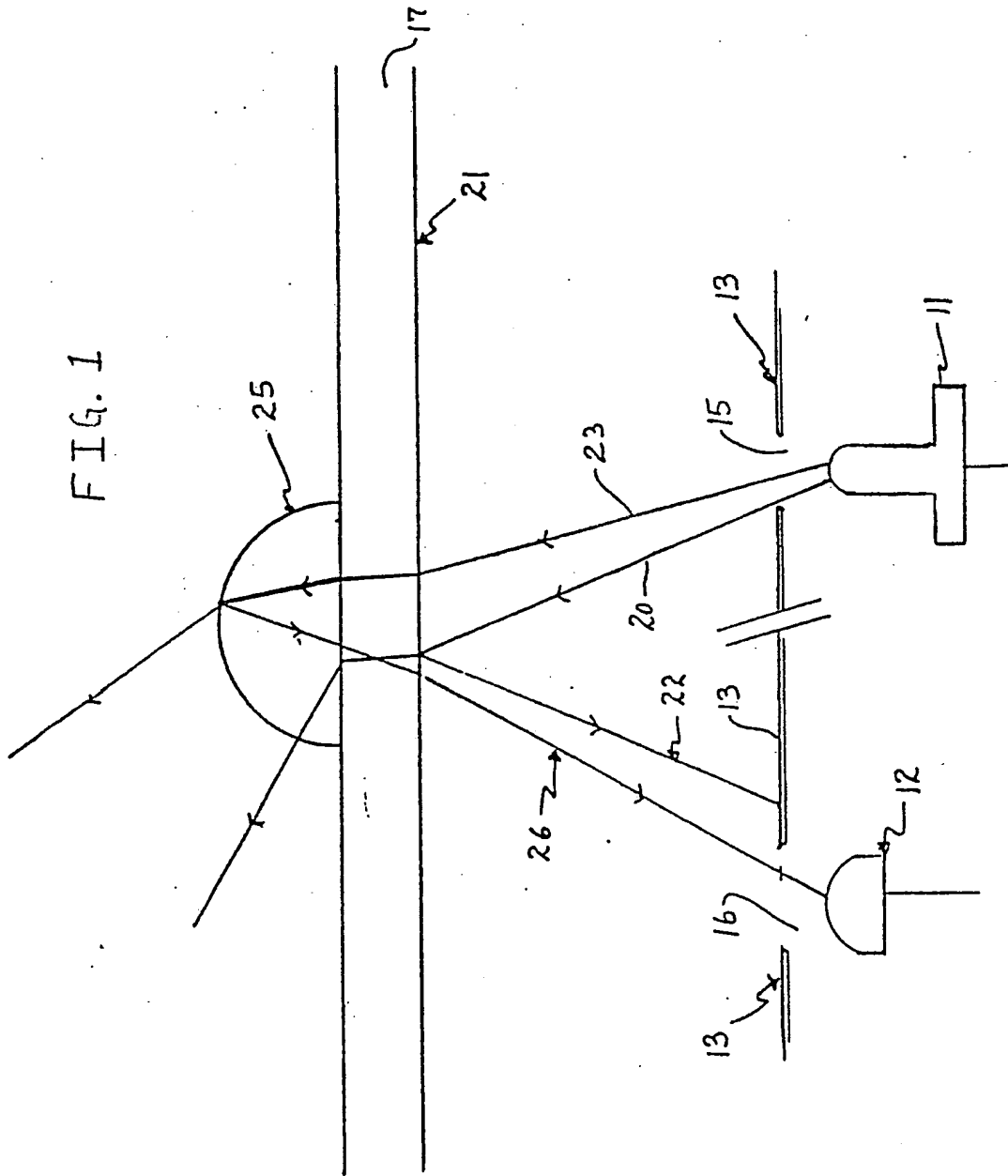




FIG. 2

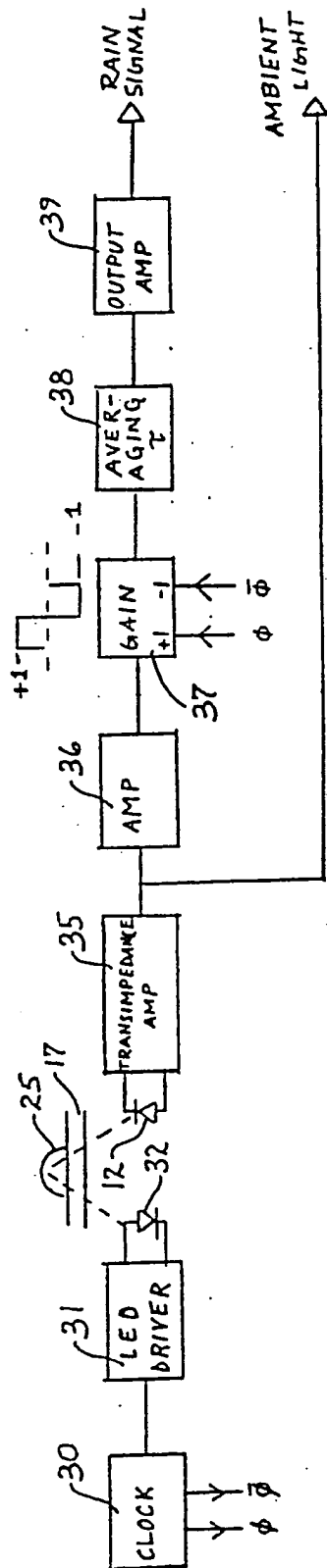


FIG. 3

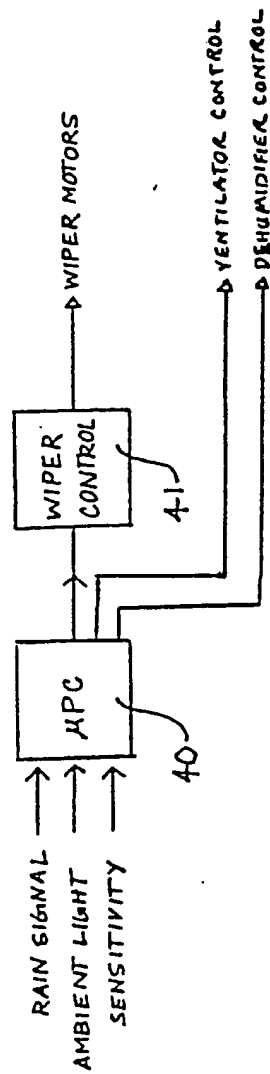


FIG. 4

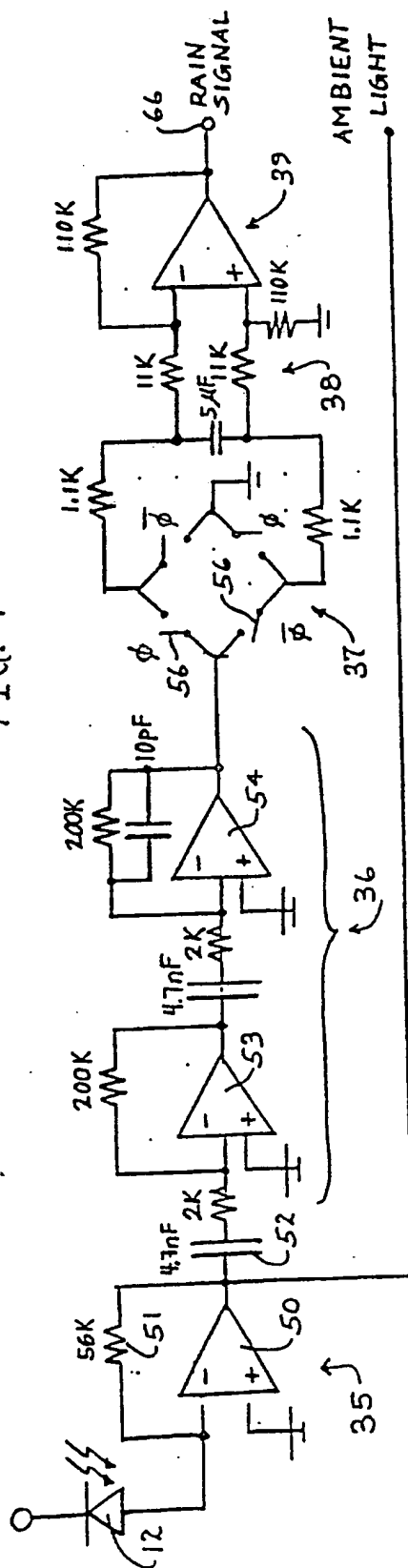
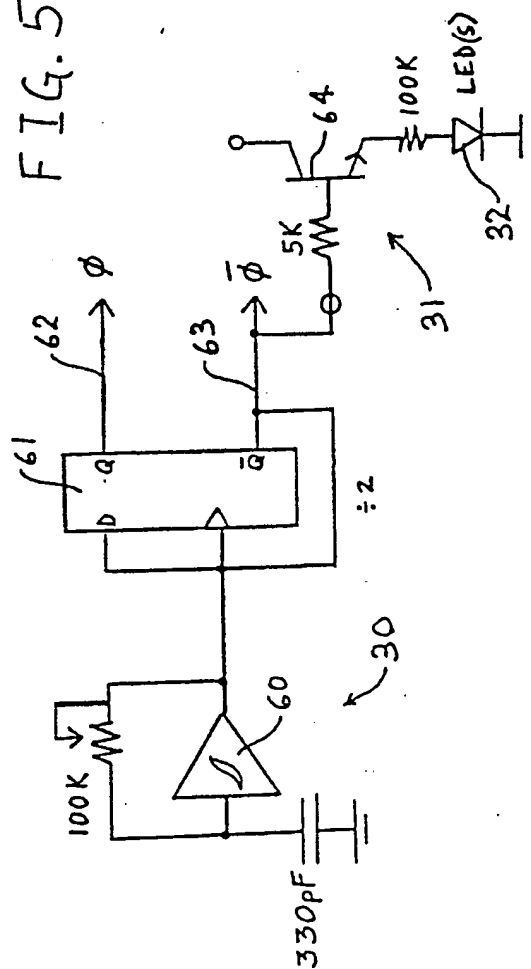


FIG. 5



## INTERNATIONAL SEARCH REPORT

International application No.

PCT/US94/05093

## A. CLASSIFICATION OF SUBJECT MATTER

IPC(5) :G08B 21/00

US CL :340/602

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 340/602,604; 15/DIG.15; 250/574; 318/DIG.2

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US, A, 4,355,271 (NOACK) 19 October 1982, see figure 1	1-5, 15-18, 20-24
Y	US, A, 4,956,591 (SCHIERBEEK et al) 11 September 1990, see figure 3	4-5, 16-18, 20-24
A	US, A, 4,620,141 (MCCUMBER et al) 28 October 1986, see abstract	1-24
A	US, A, 4,481,450 (WATANABE et al) 06 November 1984, see abstract and figure 2	1-24
A	US, A, 4,871,917 (O'FARRELL et al) 03 October 1989, see abstract and figure 9	1-24
A	US, A, 4,987,354 (STEINMANN) 22 January 1991, see abstract and figure 1	1-24

☒ Further documents are listed in the continuation of Box C.
 ☐ See patent family annex.

* "A"	Special categories of cited documents: document defining the general state of the art which is not considered to be part of particular relevance	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"E"	earlier document published on or after the international filing date	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"O"	document referring to an oral disclosure, use, exhibition or other means	"Z"	document member of the same patent family
"P"	document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search

21 JUNE 1994

Date of mailing of the international search report

SEP 02 1994

 Name and mailing address of the ISA/US  
 Commissioner of Patents and Trademarks  
 Box PCT  
 Washington, D.C. 20231

Facsimile No. (703) 305-3230

Authorized officer

JULIE LIU

Telephone No. (703) 308-6738

# INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US94/05093

## C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US, A, 5,059,877 (TEDER) 22 October 1991, see abstract and figure 1	1-24